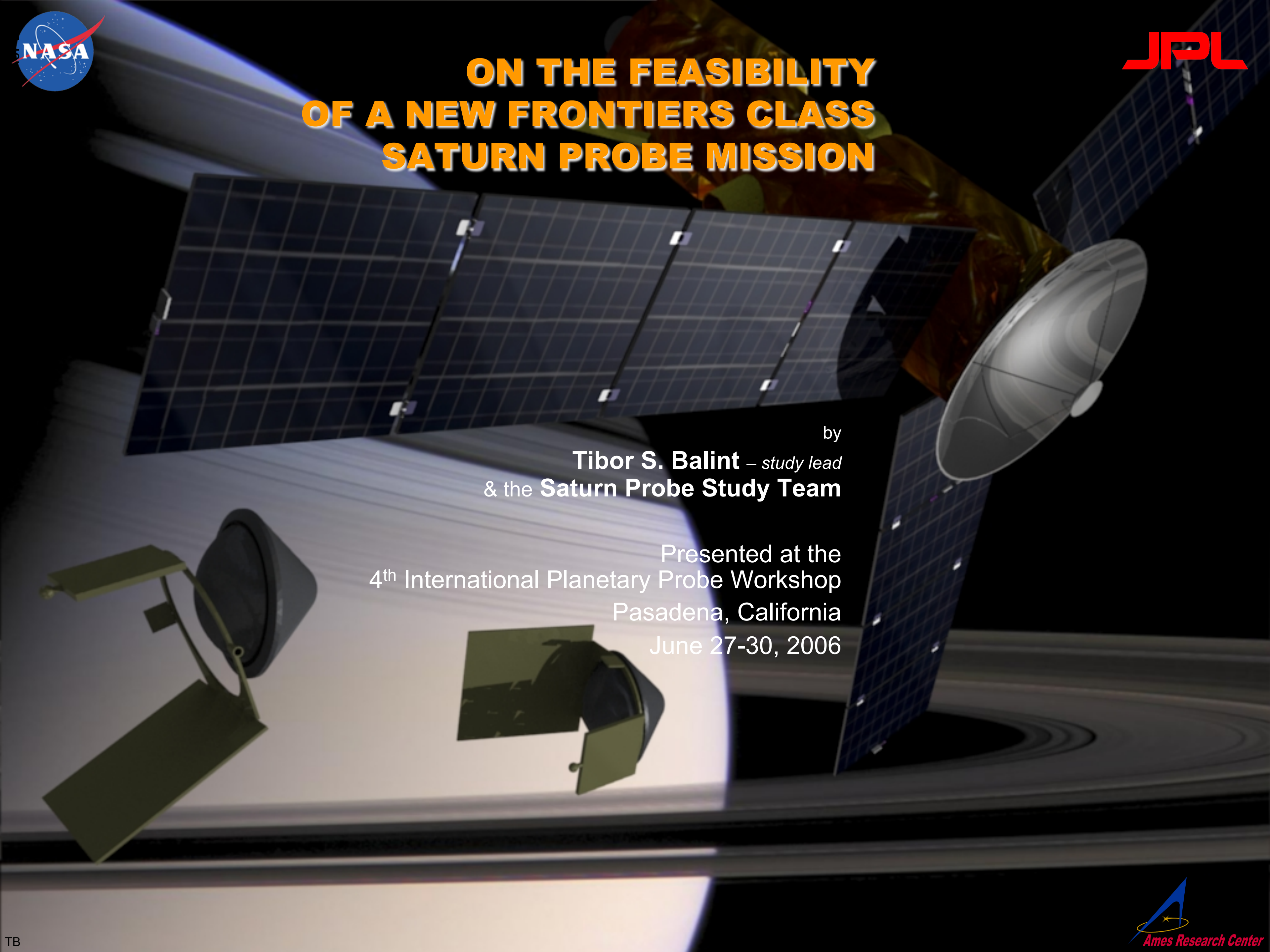

ON THE FEASIBILITY OF A NEW FRONTIERS CLASS SATURN PROBE MISSION

by

Tibor S. Balint – *study lead*

& the **Saturn Probe Study Team**

Presented at the
4th International Planetary Probe Workshop
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TB

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- Tom Spilker – Architectures, Attenuation, Science (JPL)
- Nathan Strange – Trajectories, Architectures (JPL)
- Bill Strauss – Probe entry / descent (JPL)
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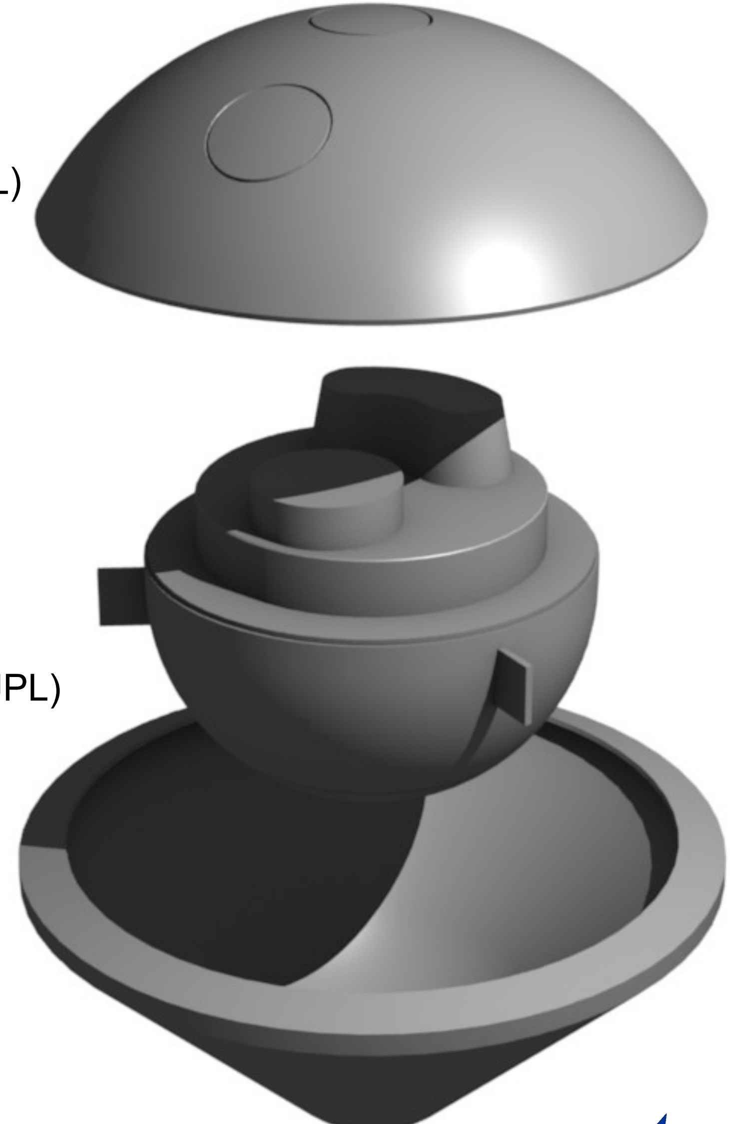

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Pre-decisional – for discussion purposes only

Caveat

- This presentation focuses strictly on
  - Science goals and strawman payload
  - Trajectories
  - Telecom / attenuation
  - Atmospheric entry, descent and TPS issues
  - Communications

- **The presentation does NOT provide a full systems engineering description**

- It is assumed that the operation for the Saturn flyby mission concept described here would last only for about 5 hours, therefore, the power requirements on the flyby spacecraft would be satisfied by the combination of solar power generation and batteries. Longer missions at this distance from the Sun would likely require internal power sources, such as RPSs.

In this study:

- For Power:
  - We could assume a Juno class solar panel configuration
- For Thermal Management:
  - On the probes we would likely require RHUs for component heating

The views and opinions expressed here are those of the author and does not necessarily represent official NASA policy.

Overview

- **Introduction:**
  How does the Saturn Flyby with Shallow Probes mission fit into the SSE Roadmap?

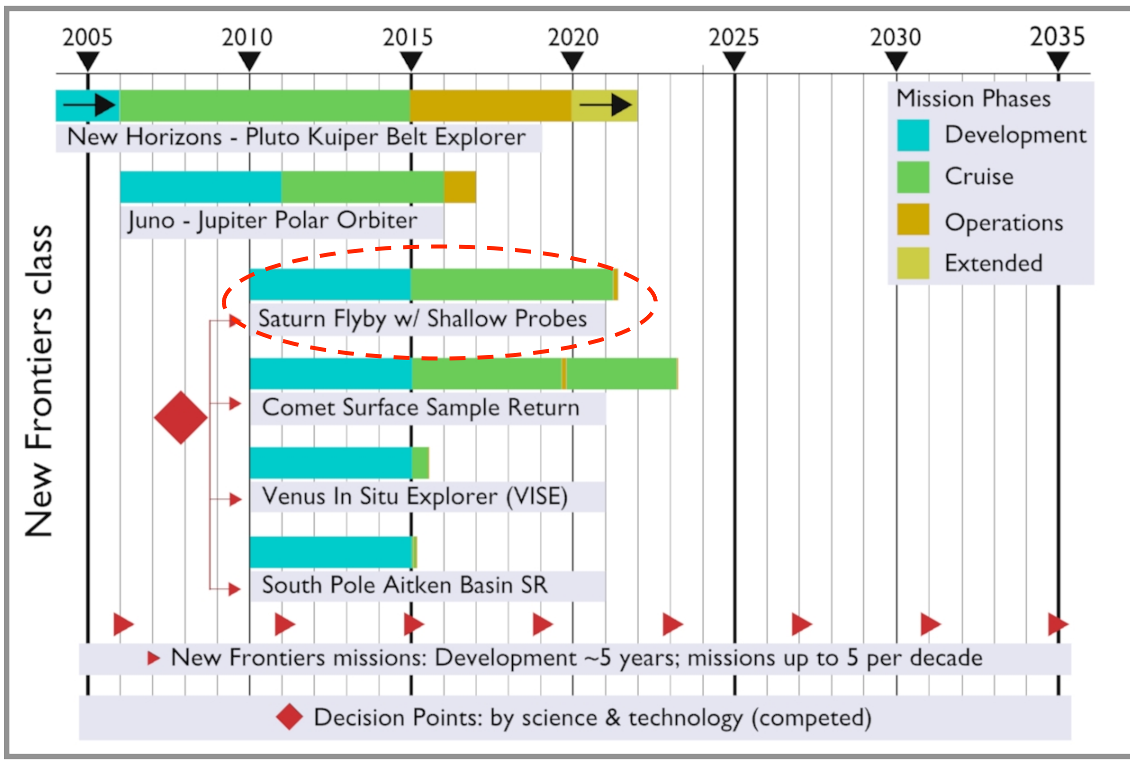
- **Questions to be answered in this presentation:**
  1: What are the Science Objectives & Instruments?
  2: What is the mission "wish list" & a representative mission architecture?

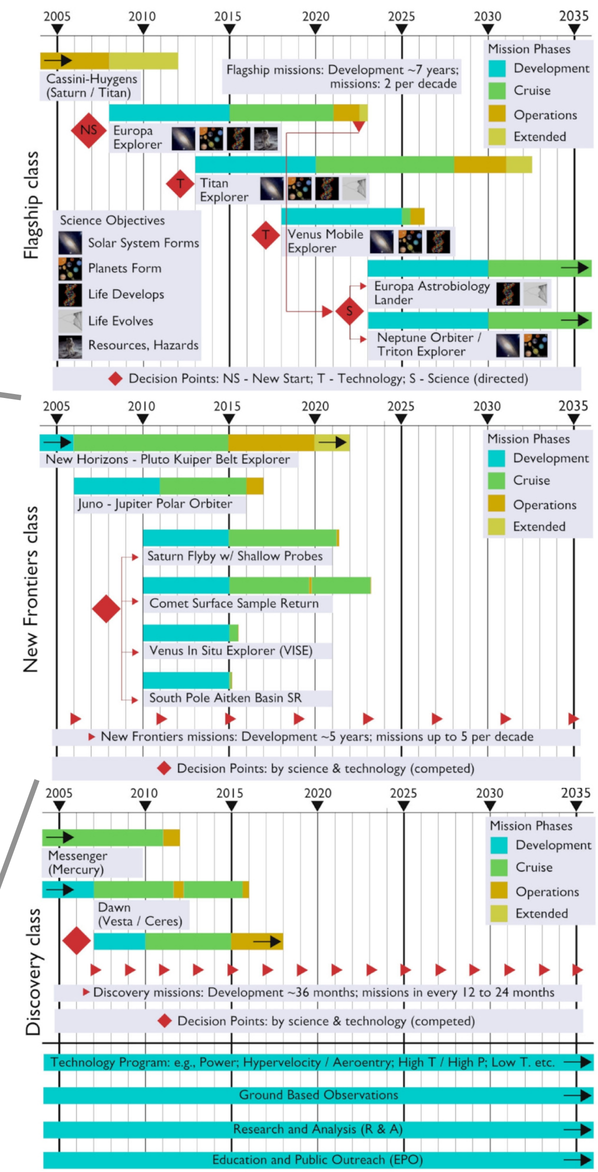
  3: How to get from Earth to Saturn?
  4: What is an "ideal flyby" at Saturn?
  5: Can we / How to do microwave radiometry?
  6: Any issues with atmospheric entry and descent?
  7: Can we communicate back the probe data?
  8: Can we do Direct to Earth communication from the probe?

- **Conclusions**

Saturn Probes & the 2006 SSE Roadmap

- The **2006 SSE Roadmap** is currently under way
- It identifies a **New Frontiers Class Saturn Flyby with Probes Mission** as one of the options for the next New Frontiers opportunity
- **The goal is to demonstrate that we can do this**



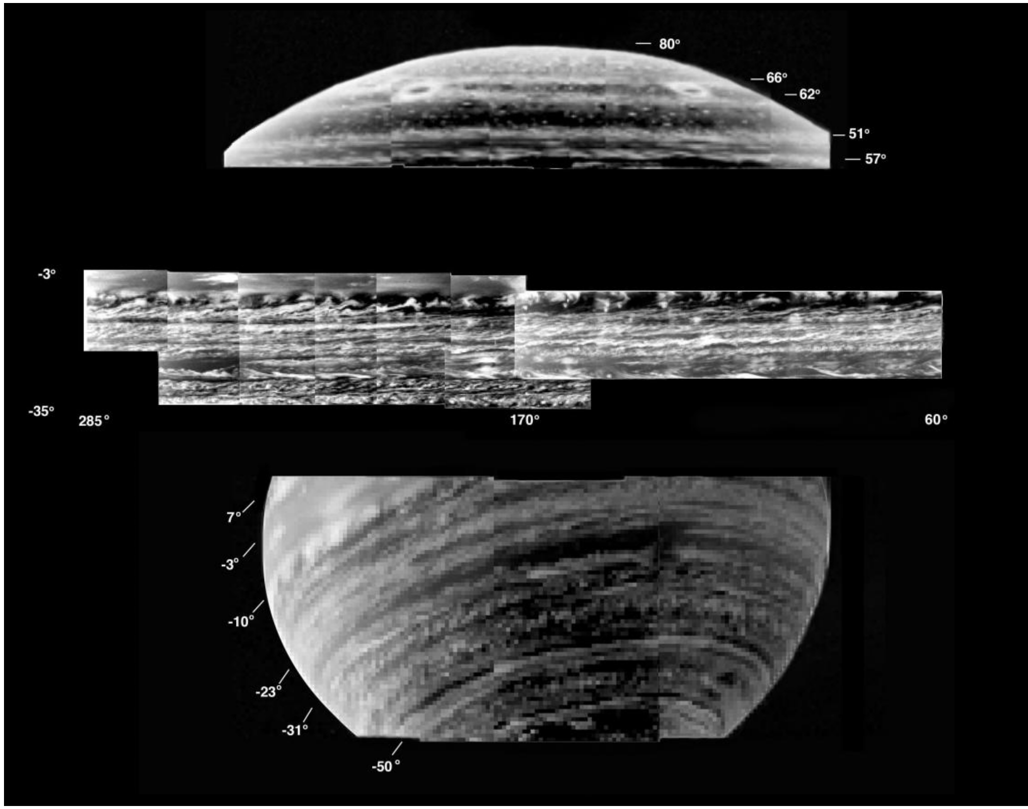


Ref: Solar System Roadmap 2006

What are the Science Objectives?

Key: Comparative planetology of well-mixed atmospheres of the outer planets is key to the origin and evolution of the Solar System, and, by extension, Extrasolar Systems (Atreya et al., 2006)

- The key science objectives that would be addressed by the Saturn Probe mission are:
  - **Origin and Evolution** – <u>Saturn atmospheric elemental ratios</u> relative to hydrogen (C, S, N, O, He, Ne, Ar, Kr, Xe) and key isotopic ratios (e.g., D/H, $^{15}N/^{14}N$, $^{3}He/^{4}He$ and other noble gas isotopes), <u>gravity and magnetic fields</u>; <u>He relative to solar, Jupiter</u>. [P, C]
  - **Planetary Processes** – <u>Global circulation, dynamics, meteorology</u>. <u>Winds</u> (Doppler and cloud track), <u>interior processes</u> (by measuring disequilibrium species, such as PH_3, CO, AsH_3, GeH_4, SiH_4). [P, C]



NASA – Cassini: PIA03560: A Gallery of Views of Saturn's Deep Clouds

Ref: Atreya, S. K. et al., (2006) Multiprobe exploration of the giant planets – Shallow probes, Proc. International Planetary Probes Workshop, Anavyssos, 2006.

Ref: Dave Atkinson

Typical Science Instruments Expected for a Saturn Probes & Flyby S/C

Shallow Probe to 10 bars	
ASI	– Atmospheric Structure
NEP	– Nephelometer
HAD	– Helium abundance
NFR	– Net flux radiometer
NMS	– Neutral mass spectrometer
LRD /EPI	– Lightning / Energetic particles
ARAD	– Ablation monitor – on TPS
DWE	– Doppler wind experiment
OPH	– Ortho-Para Hydrogen
TLS	– Tunable laser spectrometer
IMG	– Imaging
MWR	– Microwave radiometer

Flyby	
GRV	– Gravity mapping
MAG	– Magnetometer
SSI	– Imaging
DWE	– Doppler Wind Experiment

- This **might be** an **oversubscribed** strawman payload set
- The actual number of instruments would be dictated by the final mission cost, fixed at $750M FY05 for a NF mission *(Juno)*
- **We assumed the same instrument sampling rate per distance traveled as used on the Galileo probe**

Ref: Dave Atkinson, Bill Smythe (with comments from Sushil Atreya)

What is the mission “wish list” & a typical mission architecture?

Science community “wish list” for mission success:

- Saturn Flyby with two (2) shallow probes to 10 bars
- Microwave radiometry to ~100 bars
- Probe 1: equatorial probe (0°), and
- Probe 2: mid-latitude probe (-45°)

Representative mission architecture assumptions:

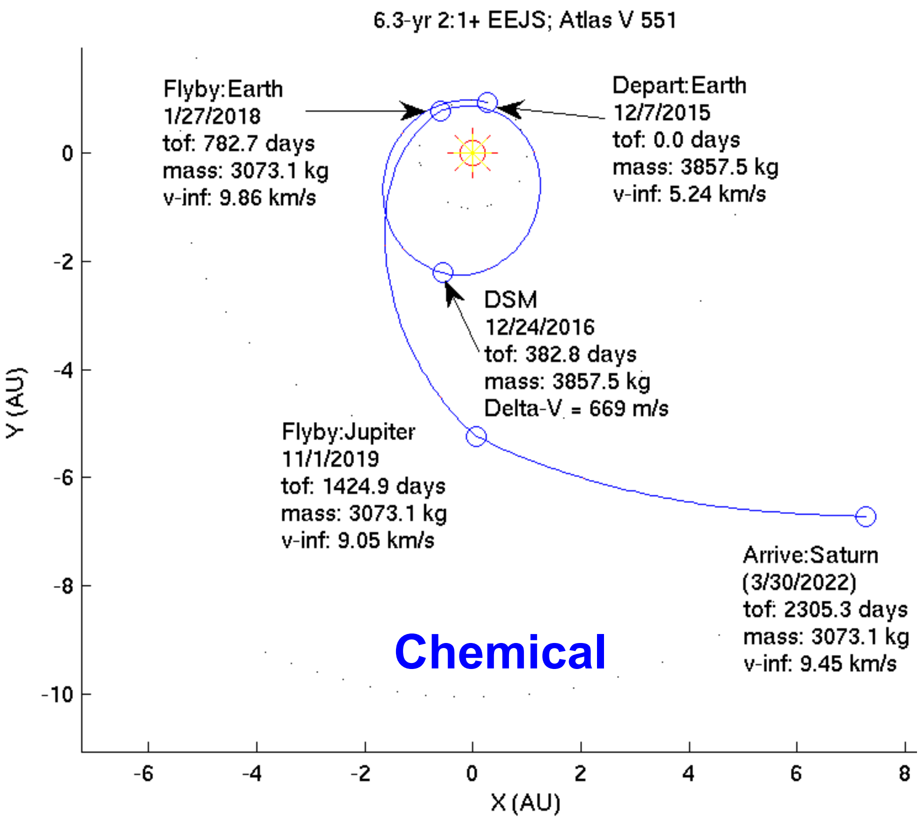
- Identical Galileo class probes; Spin stabilized
- (a) Chemical propulsion or (b) SEP (to get there)
- Multiple Gravity Assist (to increase delivered mass)
- Probes Released 6 months before Saturn flyby (the same way as Galileo did it)
- Go between F and G rings ~2.34-2.82 R_s (2.634 R_s – where Cassini passed, to avoid ring particles)
- UHF communication between probes and flyby S/C
- X-band from Flyby S/C to Earth
- Power sources considered in this study:
  - On flyby S/C: LILT-solar / batteries
  - On probes: primary batteries

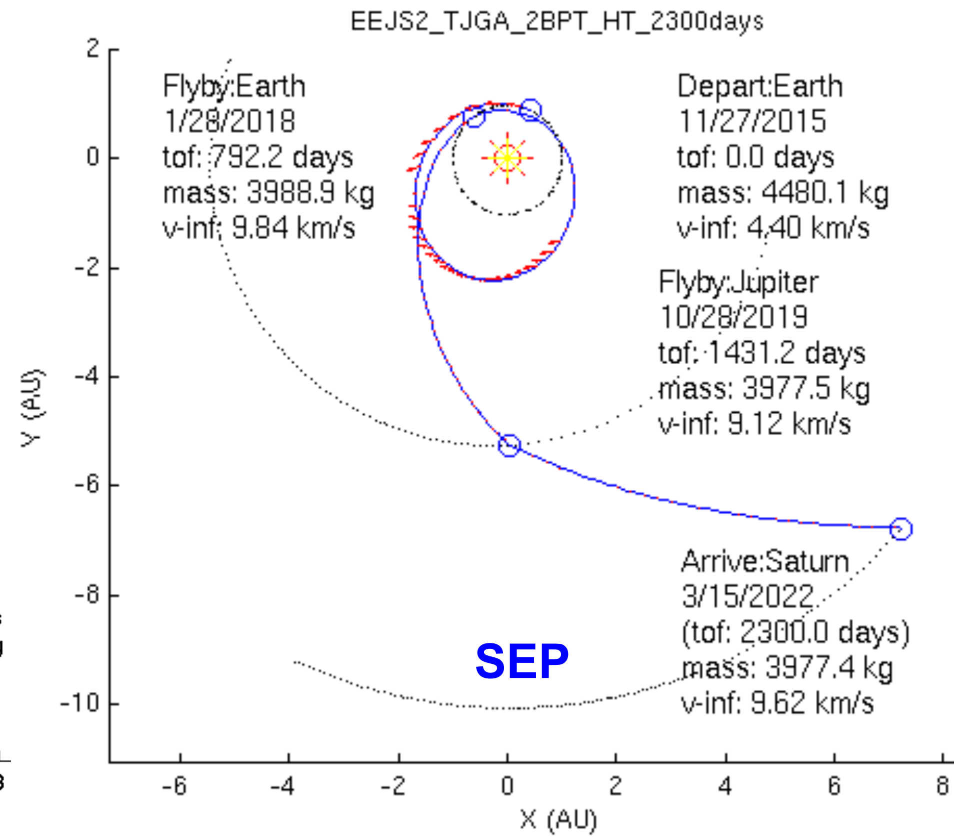
Ref: T. Spilker, T. Balint, N. Strange, W. Folkner, & the Saturn Probe Study Team, with input from S. Atreya and D. Atkinson on science rationale

Chemical & SEP Options for the Same Representative Trajectory

- **2015 Launch – 6.3 years flight time – EEJS Gravity Assist Trajectory**

- For the **same flight time** the **SEP** system delivers approximately **30% more** mass to Saturn for our case; or the same mass at a smaller L/V



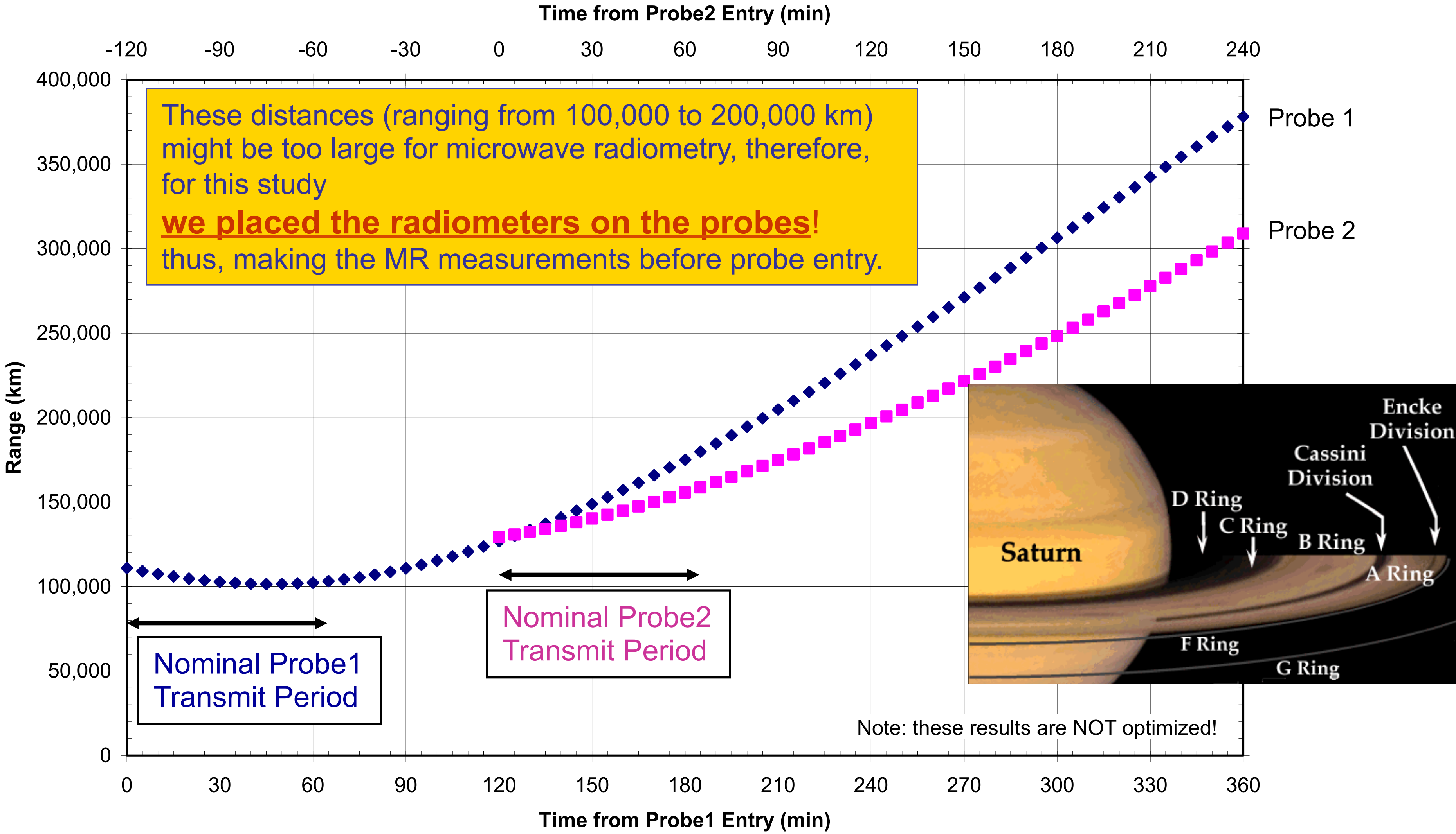


Prepared by T. Balint, JPL – June 27, 2006

Ref: Theresa Kowalkowski, Try Lam

Saturn Arrival Geometry – Passing Through the F & G Ring Gap

Flying inside the rings:	good distance / short visibility, telecom window
Flying outside the rings:	too far / but long telecom window



NOTE: Range & elevation calculations are made with respect to a fixed point rotating with Saturn

Ref: Theresa Kowalkowski, Try Lam

Probe Entry / Aeroshell

Entry direct.	Latitude deg	Rel. entry V, km/s	Max diam.,m	Entry mass, kg	Max. heat rate*, kW/cm^2	Forebody TPS mass fraction	Est. total TPS mass fraction+ (+ zero margins)	Max. decel., g
Pro.	6.5	26.8	1.265	335	2.66	0.235	0.258	43.6
Pro.	6.5	26.8	0.8	130	3.27	0.243	0.267	43.3
Pro.	-45	29.6	0.8	130	4.44	0.256	0.282	47.7
Pro.	-45	29.6	1.265	335	3.67	0.248	0.273	47.9
Retro.	6.5	46.4	1.265	335	21.5	0.352	0.387	76.4
Retro.	6.5	46.4	0.8	130	22.3	0.348	0.383	75.3

Note: these table values are given for a flight path angle of -10°, whereas the trajectory calculations on Page 16 are given for -8°. At -8° the equatorial retrograde entry results in a TPS mass fraction that exceeds that of the Galieo probe.

- **TPS mass-fractions**
  - For low-latitude retrograde entries, about same as Galileo probe (~50% including margins, etc.)
  - **For prograde entries, about 30% less than Galileo**
  - Nearly same for big and small probes if m/C_DA same
- **Max. heating rates** and **max. g** about **35% of Galileo**
- **Heating pulse about 2.5 times longer** (atm. density scale height about 2.5 larger at Saturn than Jupiter)

- Saturn probes have **less ablation**, but need more insulation
- **Time to parachute deployment** is about **5 minutes**
- Time to **descend to 10 bar** altitude is about **2 hr. 26 min.** (using Galileo parachute size)
- *(note: very similar to the independent calculations by Bill Strauss)*

Ref: Mike Tauber, Gary A. Allen, Jr. and Lily Yang

Prepared by T. Balint, JPL – June 27, 2006

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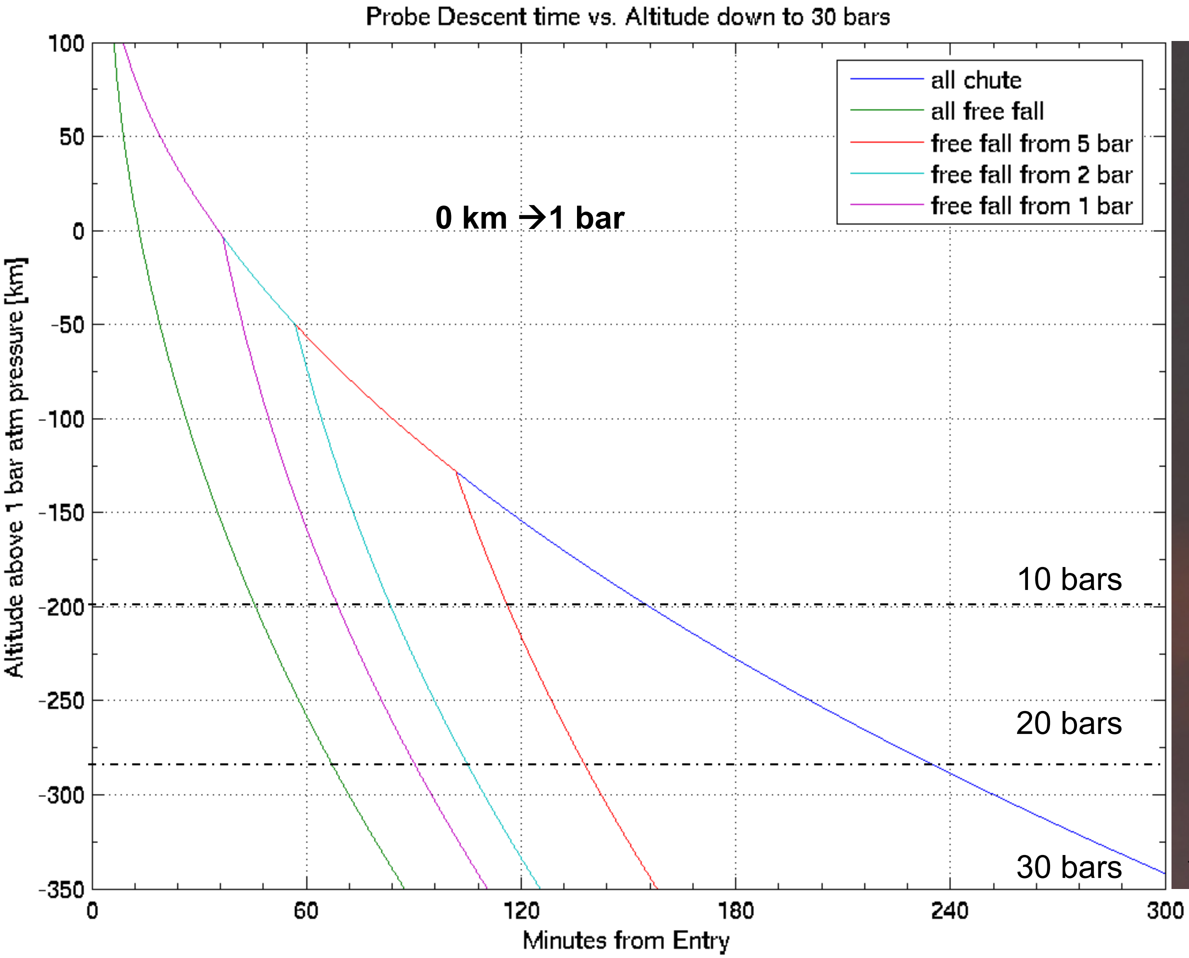
Probe Descent time vs. Altitude Down to 30 bars

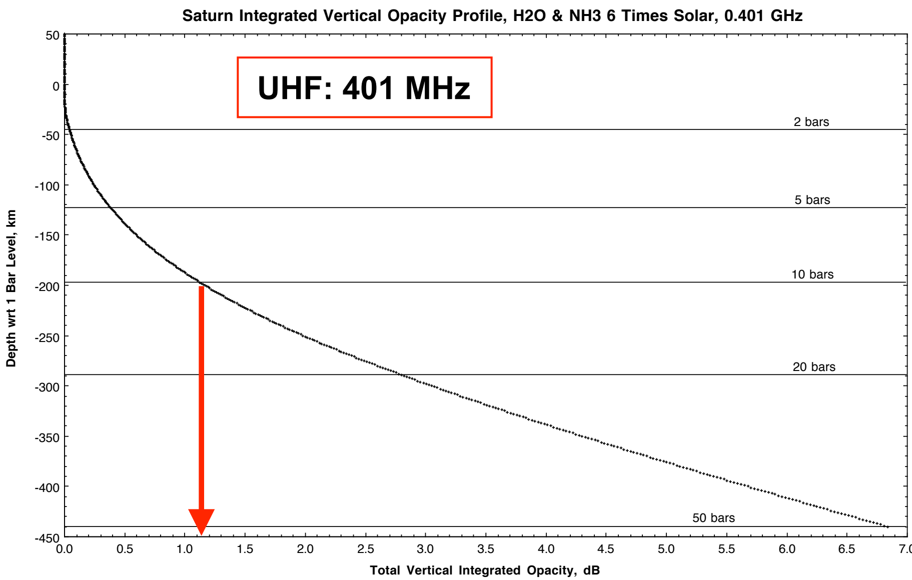


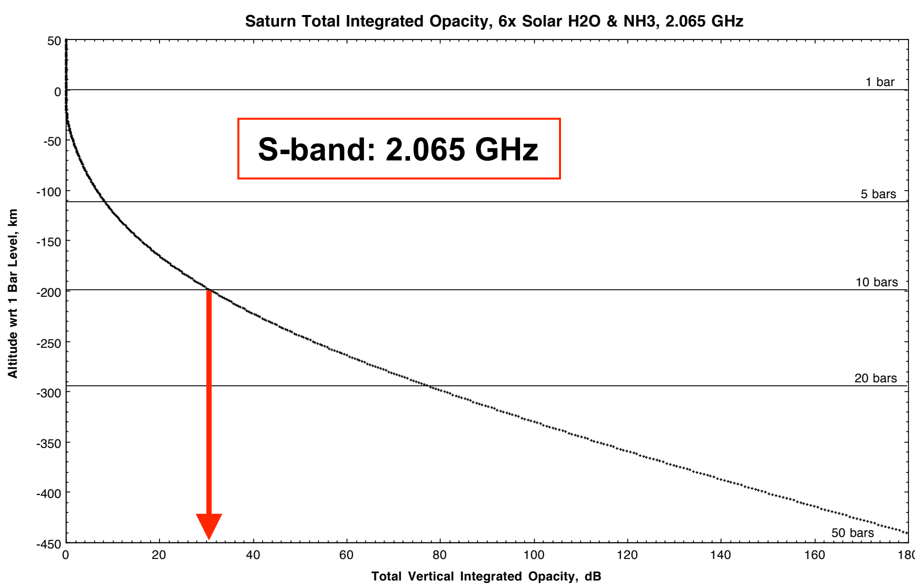
- If **free fall begins at pressure of 1 bar**, it will take **~70 minutes** from entry **to** reach **10 bars**
- *For better probe stability, the freefall phase could be replaced with descent with a smaller second parachute*
- If the descent is **entirely on the parachute**, it will take **~2.5 hours to** reach **10 bars**

Ref: Bill Strauss / Independently confirmed by Gary Allen (both using a Saturn Atmosphere Model by G. Orton)

Can we communicate back the probe data?

Attenuation in Saturn's Atmosphere





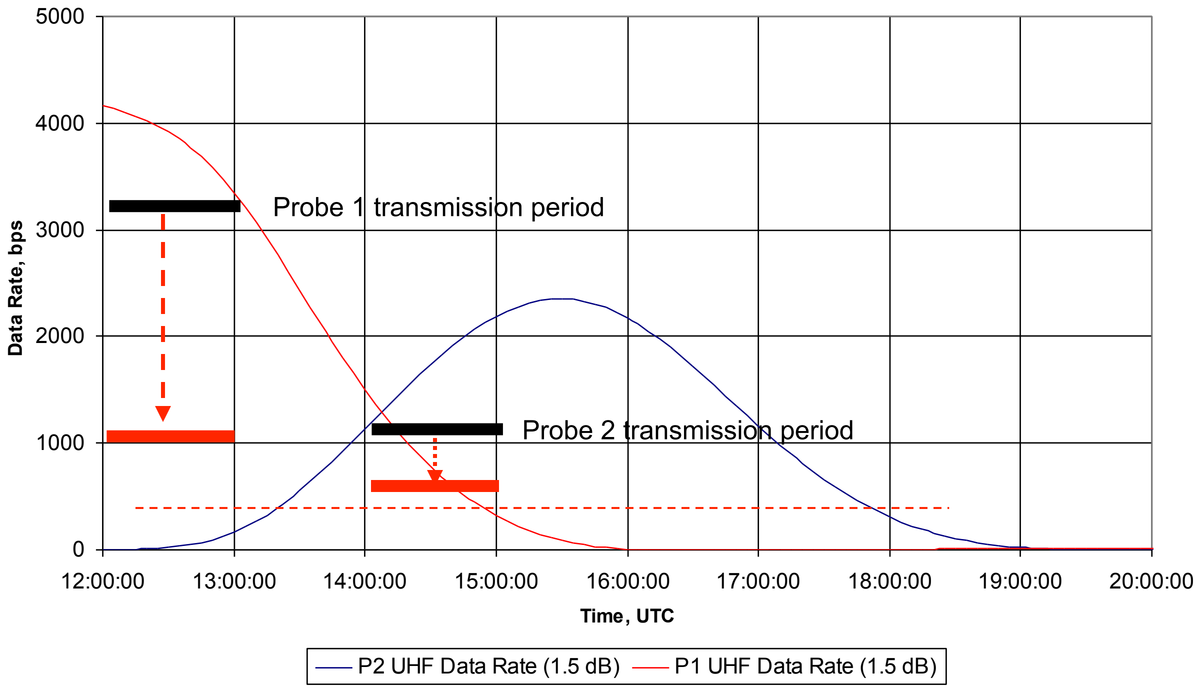
Ref: Tom Spilker

- **NOTE: This is discussed in detail by Tom Spilker in his presentation**
- **One of a kind computer code** was developed **by Tom Spilker** specifically for this study to calculate attenuation for Saturn's atmosphere
- Findings:
  Attenuation at 10 bar
  - **UHF: ~1.5 dB** (~1.2 dB + margin)
  - **S-band**: ~31 dB (**No link!**)
- These results feed directly into the telecom link budget calculations, and also impact Direct-to-Earth feasibility
- Saturn atmospheric model for Tom's calculations was provided by Glenn Orton
  - **Scale height is ~2x that of Jupiter's** ~45 km at the pressures of interest
  - However, **no radiation** environment

Can we communicate back the probe data?

Saturn Probes Proximity Data Rates at UHF

Saturn Probes UHF Data Rates
1.5 dB Vertical Atmospheric Attenuation



From Probe to Flyby S/C

Point design resulted in a lower data rate, than preliminary calc.:

Probe	data rate	(volume)
Probe 1:	1024 bps	(~3.7 Mb)
Probe 2:	512 bps	(~1.9 Mb)

Still sufficient to upload the data to the flyby S/C, including the additional ~1.5Mbits stored from the Microwave Radiometry and piggybacked with the normal probe data.

With the current trajectories, studied here, **neither probe has line-of-sight to Earth** during atmospheric descent

Flyby would be occulted ± 20 minutes around Probe 2's prime transmit time

Consequently, we assumed **store and dump** operation

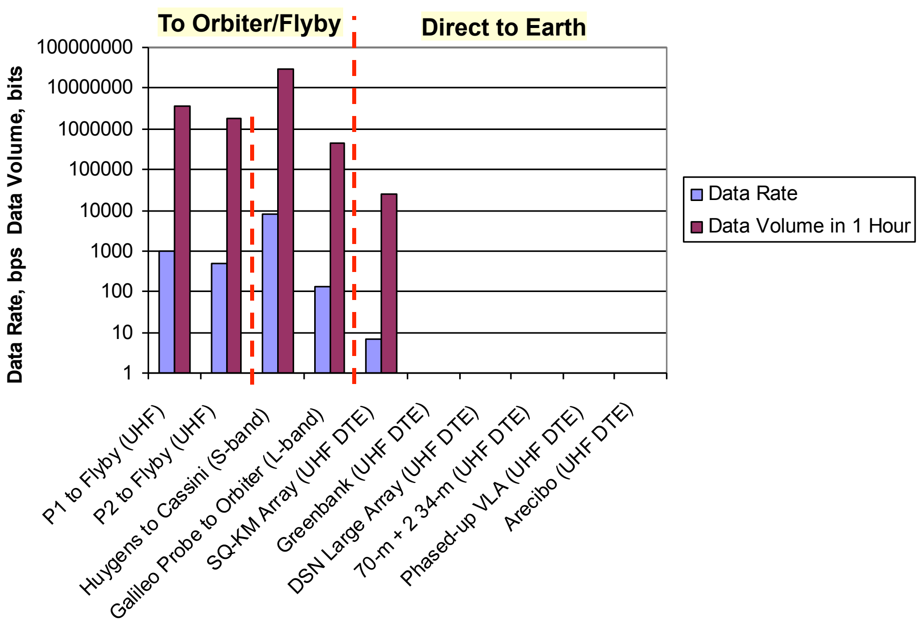
From Flyby S/C to Earth

The data from the two probes would be relayed back to Earth at X-band using a 35-W TWTA and 3-m diameter antenna to a 34-m antenna within the first two hours of a single tracking pass

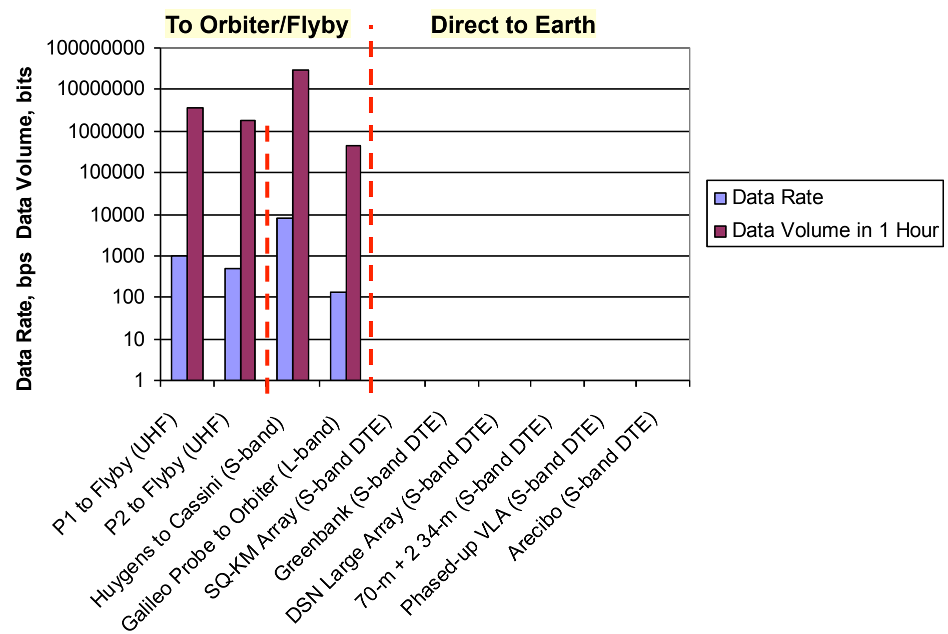
Ref: David Morabito, Anil Kantak and Arv Vaisnys

Telecom: DTE Communications:
Direct-to-Earth from Saturn using UHF and S-band

UHF Case



S-band Case



Case	UHF Data Rate (bps)	UHF Data Volume (bits)
P1 to Flyby (UHF)	1024	3686400
P2 to Flyby (UHF)	512	1843200
Huygens to Cassini (S-band)	8192	29491200
Galileo Probe to Orbiter (L-band)	128	460800
SQ-KM Array (UHF DTE)	7	25200
Greenbank (UHF DTE)	0	0
DSN Large Array (UHF DTE)	0	0
70-m + 2 34-m (UHF DTE)	0	0
Phased-up VLA (UHF DTE)	0	0
Arecibo (UHF DTE)	0	0

To Orbiter/Flyby

Direct to Earth

Case	Data Rate (bps)	Data Volume (bits)
P1 to Flyby (UHF)	1024	3686400
P2 to Flyby (UHF)	512	1843200
Huygens to Cassini (S-band)	8192	29491200
Galileo Probe to Orbiter (L-band)	128	460800
SQ-KM Array (S-band DTE)	0	0
Greenbank (S-band DTE)	0	0
DSN Large Array (S-band DTE)	0	0
70-m + 2 34-m (S-band DTE)	0	0
Phased-up VLA (S-band DTE)	0	0
Arecibo (S-band DTE)	0	0

Antenna and Telecom power on probe would be limited, and not sufficient to provide Direct to Earth communication; Probe size would limit scaling up antenna & power.

Notes – additional atmospheric attenuation makes S-band prohibitive;
For Arecibo, Saturn is outside of the declination range

Conclusions

- A proposed Saturn Flyby with Shallow Probes mission is in line with New Frontiers requirements
  - The actual cost would be based on the given point design with a suitable instrument suite
- This type of mission would not require technology development and could leverage from flight heritage, e.g.:
  - Galileo probe design/instruments; Juno solar panels and microwave radiometry; Electra UHF transceiver from the Mars program
- SEP trajectory option is comparable in cost to Chemical option
  - For the same delivered mass SEP uses a smaller L/V, offsetting SEP cost
- Thermal Protection System:
  - TPS mass fraction: For retrograde entry: Galileo-like; For prograde: ~30% less
  - For prograde entry the heating rate is at least an order of magnitude less than at Jupiter, but the heat pulse is longer
  - entry latitude is not limited by TPS
- UHF communication
  - From probes to flyby is feasible (including probe + radiometry data)
  - Direct-to-Earth communication is not NOT feasible for the expected data rate
    - Only the (not yet available) SQ KM array would be capable of any DTE data return, and only while conditions are favorable at UHF (link along vertical)
    - S-band links would be prohibitive for DTE, for this mission concept, due to significant atmospheric attenuation.

The End

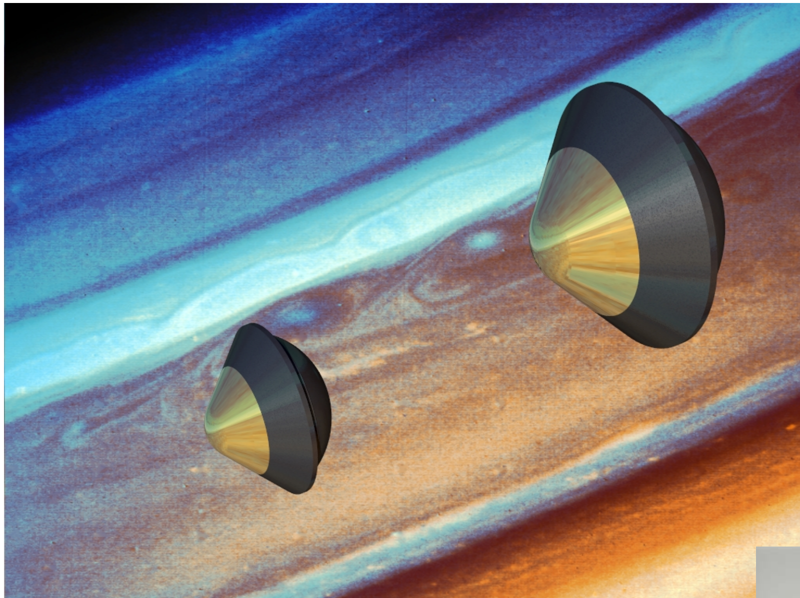
How to Reduce Mission Cost?

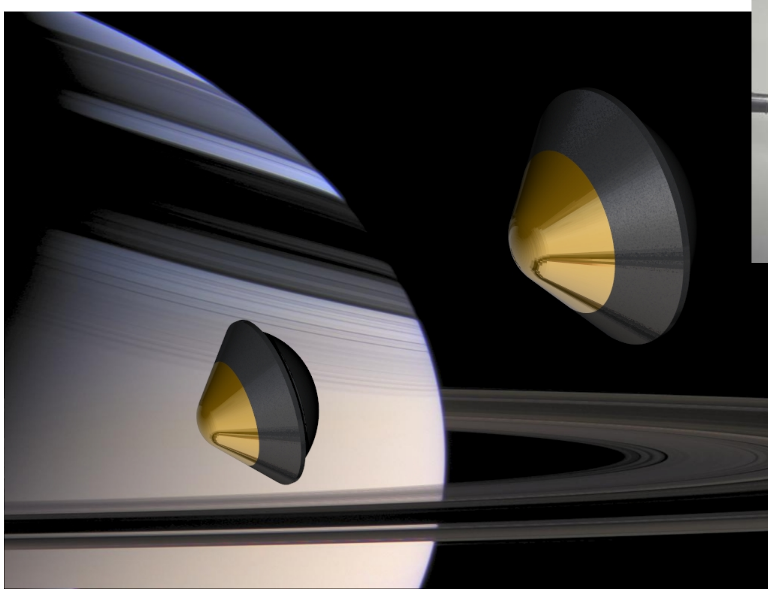
- **Assume / use** mission, instrument and design **heritage** when possible, for example:
  - Galileo probe (instruments, power system, descent module)
  - TPS (use existing materials (carbon phenolic), don't plan to restart facilities)
  - Juno (LILT solar panels, microwave radiometer)
  - Electra (telecom system)

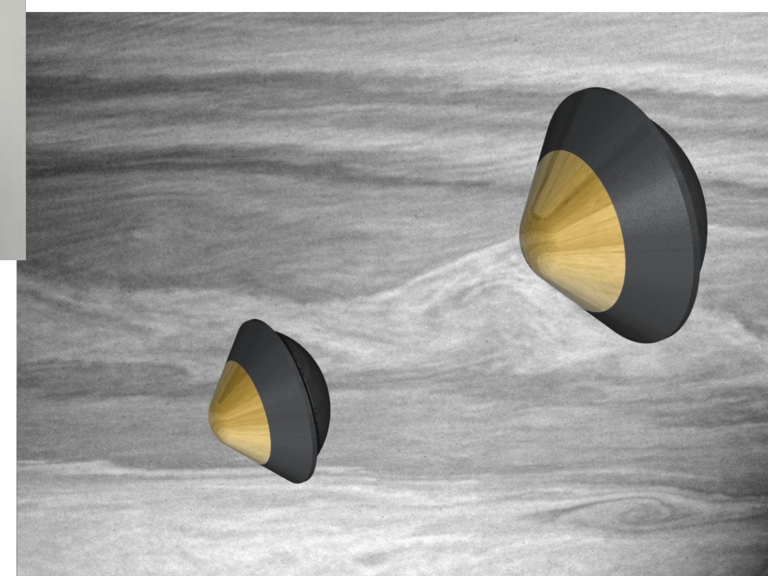
- **Minimize** science **instruments or instrument cost**
  - Descope towards minimum science requirements
  - Allow for contributed instruments

- **Simplify** mission **architecture**
  - Shorter flight times reduce operations costs
  - Use a flyby instead of an orbiter
  - Drop down in Launch Vehicles
    (by minimizing spacecraft mass)

Background info







Galileo Probe Science Instrument Accommodation

Instrument	Mass	Power	Bit rate	Volume	Special Acc. Requirements
Atmosphere structure instrument (ASI)	4.0 kg	6.3 W	18 bps	3100 cm^3	Pressure inlet port; temperature sensor outside boundary layer; 12,408 bits storage
Nephelometer (NEP)	4.8 kg	13.5 W	10 bps	3000 cm^3	Free-stream flow through sample volume; 800 bits data storage; pyro for sensor deployment
Helium abundance detector (HAD)	1.4 kg	1.1 W	4 bps	2400 cm^3	Sample inlet port
Net flux radiometer	3.0 kg	10.0 W	16 bps	3500 cm^3	Unobstructed view 60° cone +/-45° with respect to horizontal
Neutral mass spectrometer (NMS)	12.3 kg	29.3 W	32 bps	9400 cm^3	Sample inlet port at stagnation point
Lighting and radio emission detector/ energetic particle detector (LRD/EPI)	2.5 kg	2.3 W	8 bps	3000 cm^3	Unobstructed 4P Sr FOV; RF transparent section of aft cover, 78° full cone view at 41° to spin axis
Total	**28 kg**	**62.5 W**	**128 bps$^+$**	**24,400 cm^3**	

$^+$ *including playback of entry data and miscellaneous allocation: 40 bps*

Ref.s: Proc. AIAA'83, 21st Aerospace Science Meeting, Jan. 10-13, 1983, Reno, NV & Personal communications with Rich Young, February 2005

Note: Instrument suite sizes pressure vessel mass / volume / thermal

Galileo Probe Science Instruments

Instrument	Description
Atmosphere Structure Instrument	Provides information about temperature, density, pressure, and molecular weight of atmospheric gases. These quantities were determined from the measured deceleration of the Probe during the atmospheric entry phase. During the parachute-descent phase, the temperature and pressure were measured directly by sensors extending from the body of the spacecraft.
Neutral Mass Spectrometer	Analyzes the composition of gases by measuring their molecular weights.
Nephelometer	Locates and measures cloud particles in the immediate vicinity of the Galileo Probe. This instrument uses measurements of scatterred light from a laser beam directed at an arm extending from the Probe to detect and study cloud particles.
Lightning and Radio Emissions Detector	Searches and records radio bursts and optical flashes generated by lightning in Jupiter's atmosphere. These measurements are made using an optical sensor and radio receiver on the Probe.
Helium Abundance Detector	Determines the important ratio of hydrogen to helium in Jupiter's atmosphere. This instrument accurately measures the refractive index of Jovian air to precisely determine the helium abundance.
Net Flux Radiometer	Senses the differences between the flux of light and heat radiated downward and upward at various levels in Jupiter's atmosphere. Such measurements can provide information on the location of cloud layers and power sources for atmospheric winds. This instrument employs an array of rotating detectors capable of sensing small variations in visible and infrared radiation fluxes.
Energetic Particles Instrument	Used before entry to measure fluxes of electrons, protons, alpha particles, and heavy ions as the Probe passes through the innermost regions of Jupiter's magnetosphere and its ionosphere.
Relay Radio Science Experiments	Variations in the Probe's radio signals to the Orbiter will be used to determine wind speeds and atmospheric absorptions.
Doppler Wind Experiment	Uses variations in the frequency of the radio signal from the Probe to derive variation of wind speed with altitude in Jupiter's atmosphere.

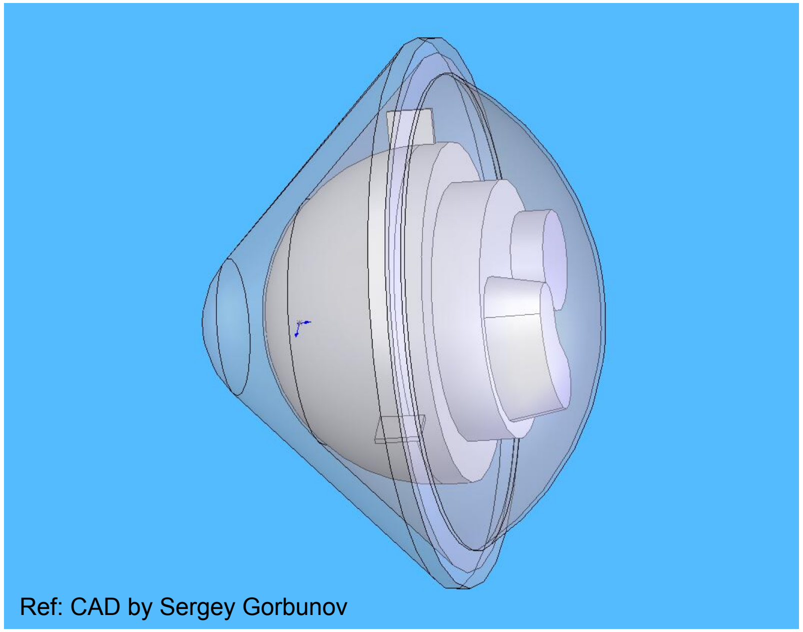
Ref: Personal communications with Rich Young, February 2005

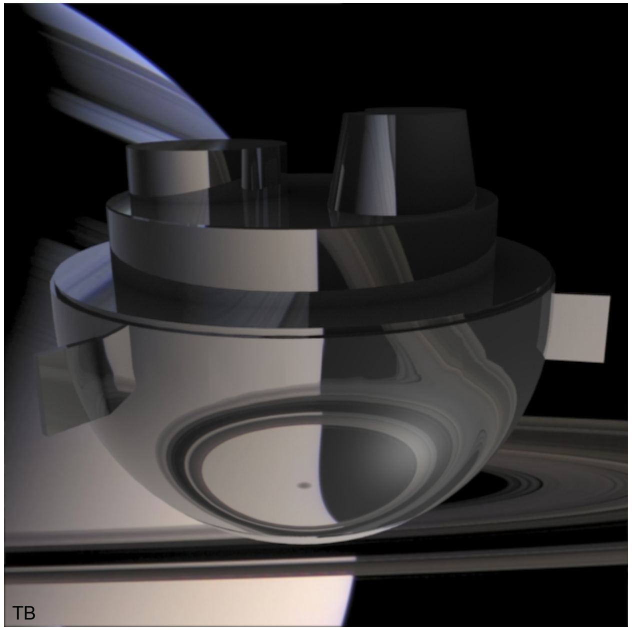
Trade Elements & Decision Drivers

Mission Class *(key study driver)*	Discovery Class	**New Frontiers Class**	Flagship Class			
Launch vehicle *(lower cost)*	Atlas V 551	Atlas V 541	**Atlas V 531**	Atlas V 521	**Atlas V 511**	
Trajectory *(target mission timeframe)*	High thrust direct	**HT Gravity Assist**	Low thrust direct	**LT GA**		
Launch opportunity *(mission timeframe)*	Other 2015 +	2015 EVEVEJS	EVVEJS	**EEJS**	EJS	Direct
Architecture *(lower cost)*	Orbiter with Probe(s)	**Flyby with Probe(s)**				
Approach *(comm, TPS)*	Polar approach	**Equatorial approach, prograde**	**Eq. approach, retrograde**			
Number of probes *(science)*	None	One	**Two**	Three	Four or more	
Probe size *(heritage)*	Half size (dimensions)	**Galileo class**	Half size (mass)			
Descent module(s) *(simplicity)*	**Single descent**	Two or multiple descents				
Descent depth *(science)*	5 bars	**10 bars**	20 bars	50 bars	100 bars	200 bars
Descent mode *(visibility, comm, extr.env)*	Parachute only	**Chute 1bars+freefall 10 bars**	Freefall to 10 bars			
Telecom Architecture *(physics)*	**Orbiter/Flyby Store and Dump Relay Telecom**	Direct-to-Earth Telecom				

Demonstrate the feasibility of a
Saturn Flyby with Shallow Entry Probes
mission within the New Frontiers Category
in support of the SSE Roadmap

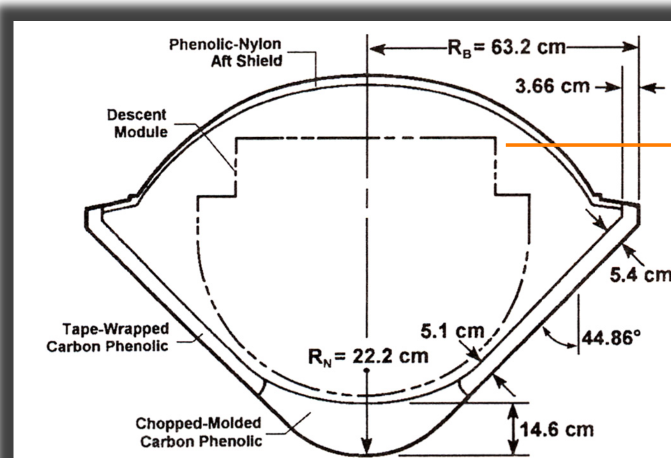
Achieving this can be a tall order, therefore, we may have to take measures to reduce cost

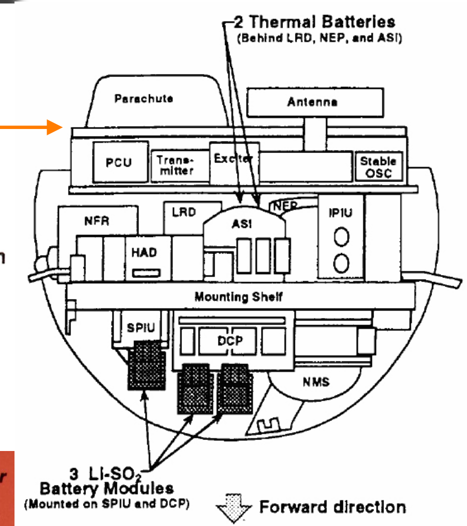


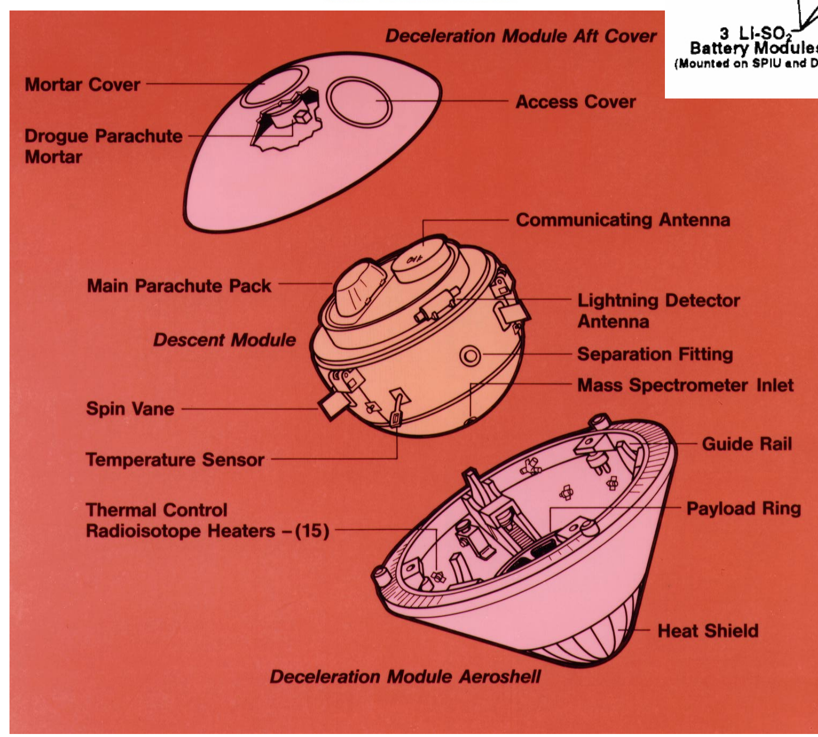


Science Instruments:
Probe Design: Galileo Probe Heritage

Item / Subsystem	Mass (kg)	Mass Subtotals (kg)
Deceleration Module		221.8
Forebody heat shield	152.1	
Afterbody heat shield	16.7	
Structure	29.2	
Parachute	8.2	
Separation hardware	6.9	
Harness	4.3	
Thermal control	4.4	
Descent module		117.1
Communications subsystem	13.0	
C&DH subsystem	18.4	
Power subsystem	13.5	
Structure	30.0	
Harness	9.1	
Thermal control	4.3	
Science instruments	28.0	
Separation hardware	0.9	
Probe Total		**338.9**







Science Instruments:

(ASI)
Atmosphere structure instrument

(NEP)
Nephelometer

(HAD)
Helium abundance detector

(NFR)
Net flux radiometer

(NMS)
Neutral mass spectrometer

(LRD/EPI)
Lighting and radio emission detector/ energetic particle detector

Ref: Galileo Probe Deceleration Module Final Report, Doc No. 84SDS2020, General Electric Re-entry Systems Operations, 1984
AIAA, "Project Galileo Mission and Spacecraft Design", Proc. 21st Aerospace Science Meeting, Reno, NV, January 10-13, 1983

- **Interplanetary trajectory** description:
  - **EEJS** (2+ ΔV-EGA)
  - **~6.3-yr** flight time
  - Arrival V_∞=9.5 km/s
- **Probes released 6 months before entry**
- Probe targeting sequence (begins 180 days before entry)
  - Probe1 release
  - Targeting maneuver
  - Probe2 release
  - Divert maneuver

Date	Time	Days from Launch	Event
12/7/2015	5:47:54	0.00	Launch
12/24/2016	0:04:47	382.76	DSM
1/26/2018	12:36:34	781.28	Earth flyby
10/29/2019	16:13:04	1422.43	Jupiter flyby
10/1/2021	12:00:00	2125.26	Probe1 release
10/11/2021	12:00:00	2135.26	Targeting maneuver
10/16/2021	12:00:00	2140.26	Probe2 release
10/21/2021	12:00:00	2145.26	Divert maneuver
3/30/2022	12:00:00	2305.26	Probe1 entry
3/30/2022	13:00:00	2305.30	Flyby s/c crosses ring plane
3/30/2022	13:05:00	2305.30	End Probe1 prime transmit
3/30/2022	13:40:00	2305.33	Earth occulted by Saturn
3/30/2022	14:00:00	2305.34	Probe2 entry
3/30/2022	15:05:00	2305.39	End Probe2 prime transmit
3/30/2022	15:15:00	2305.39	Exit occultation
3/30/2022	15:20:00	2305.40	Begin data playback

- Targeting notes
  - 10 days between each maneuver
  - “Entry” defined as reaching altitude of 1,000 km (oblate Saturn)
    - Targeted flight path angle = -8°
  - **Flyby S/C crosses the ring plane in the F & G gap**
    - Crosses 60 min. after Probe1 entry
    - 150,000 km radius at 0° latitude
  - **Probe1** targeted to **0° latitude**
    - Longitude ends up at 140.9°
    - Radius is 61,268 km
  - **Probe2** targeted to **-45° latitude**
    - Longitude ends up at 72.8°
    - Radius is 58,088 km
    - **Enters 2 hours after Probe1 entry**
    - Crosses ring plane at radius of 480,000 km (outside edge of E-ring)

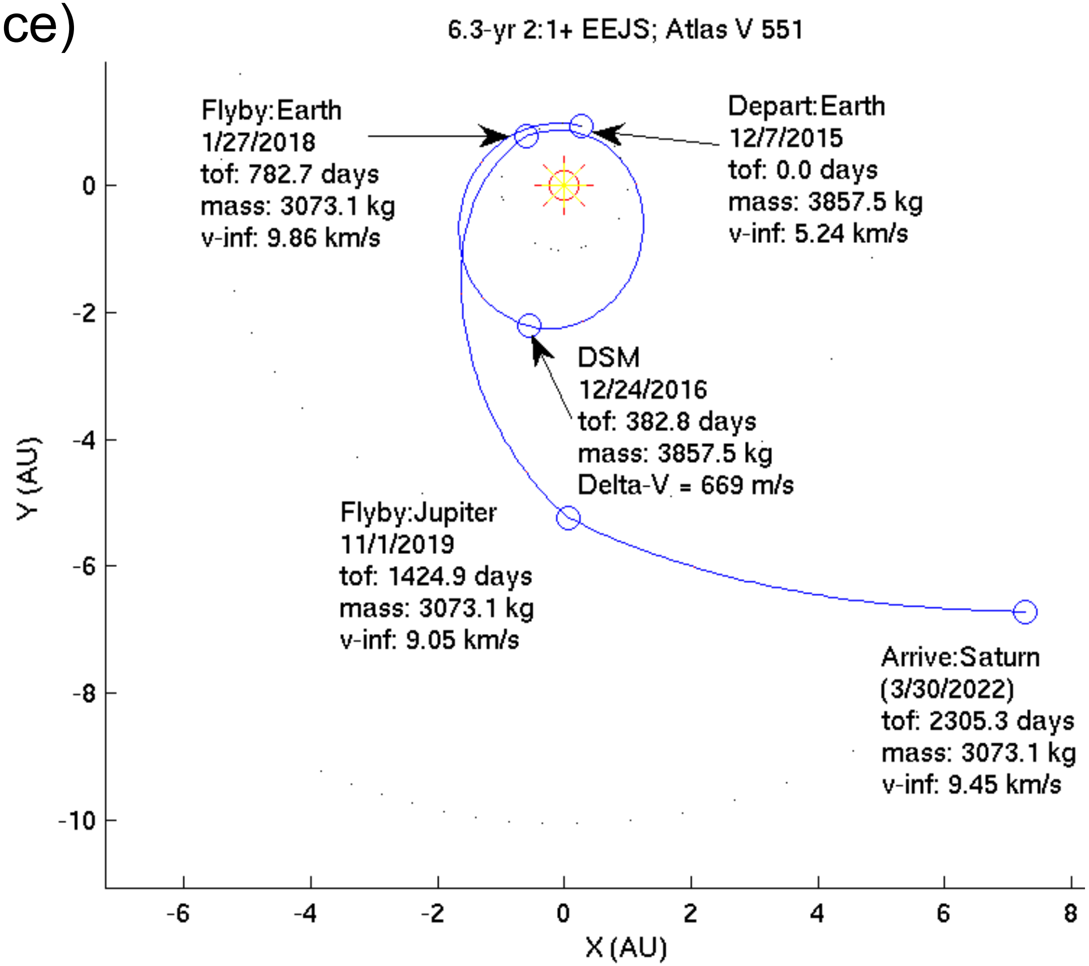
Ref: Theresa Kowalkowski, Try Lam

Representative Baseline Trajectory

- Probe trajectories were constructed based off a representative trajectory
  - EEJS (2+ Earth resonance)
  - December 2015 Launch
  - 6.3-yr flight time

Launch Vehicle	Delivered Mass*
Delta IV - 4050H	4411 kg
Atlas V - 551	3073 kg
Atlas V - 521	2124 kg
Atlas V - 401	1566 kg
Delta IV - 4040-12	956 kg

*Deterministic and optimal performance values; does not include statistical estimates or a 21-day launch period analysis



The point design allowed us to consider a smaller Launch Vehicle, thus reducing cost

Ref: Theresa Kowalkowski, Try Lam

Delta-V Budget for the Representative Trajectory

- A break down on delivering **~3,000 kg** to Saturn:
  - An **EEJS** trajectory with a DSM can deliver ~3,000 kg to Saturn in **6.3 years** on an Atlas-V (551).
    - Using SEP the delivered mass can increase by ~1,000 kg for the same flight time, allowing for a smaller launch vehicle, the Atlas-V (521), for the same delivered mass.
  - An **EVVEJS** trajectory w/out any DSM can deliver ~3,000 kg to Saturn in 8 years on an Atlas-V (521).

- Accounting for a 21-day launch period the delivered mass is slightly lower than 3000 kg:

	Delta-V Budget (m/s)							
Launch C3 (km^2/s^2)	**DSM**	***Statistical* (inter-planetary)***	**Probe2 Targeting**	**Flyby Divert**	***Statistical* (arrival)***	**Total Deterministic**	***Total Statistical****	**Total Delta-V**
29.5	685	*100*	20	30	*35*	735	*135*	**870**

*Note that the statistical delta-v is estimated, not computed

- Assuming a main propulsion system with I_{sp}=300 s

Launch Vehicle	**Launch Mass (kg)**	**Dry Mass (kg)**
Delta IV H	5309	3950
Atlas V 551	3715	2764
Atlas V 521	2556	1902
Altas V 401	1877	1396
Delta IV 4040-12	1105	822

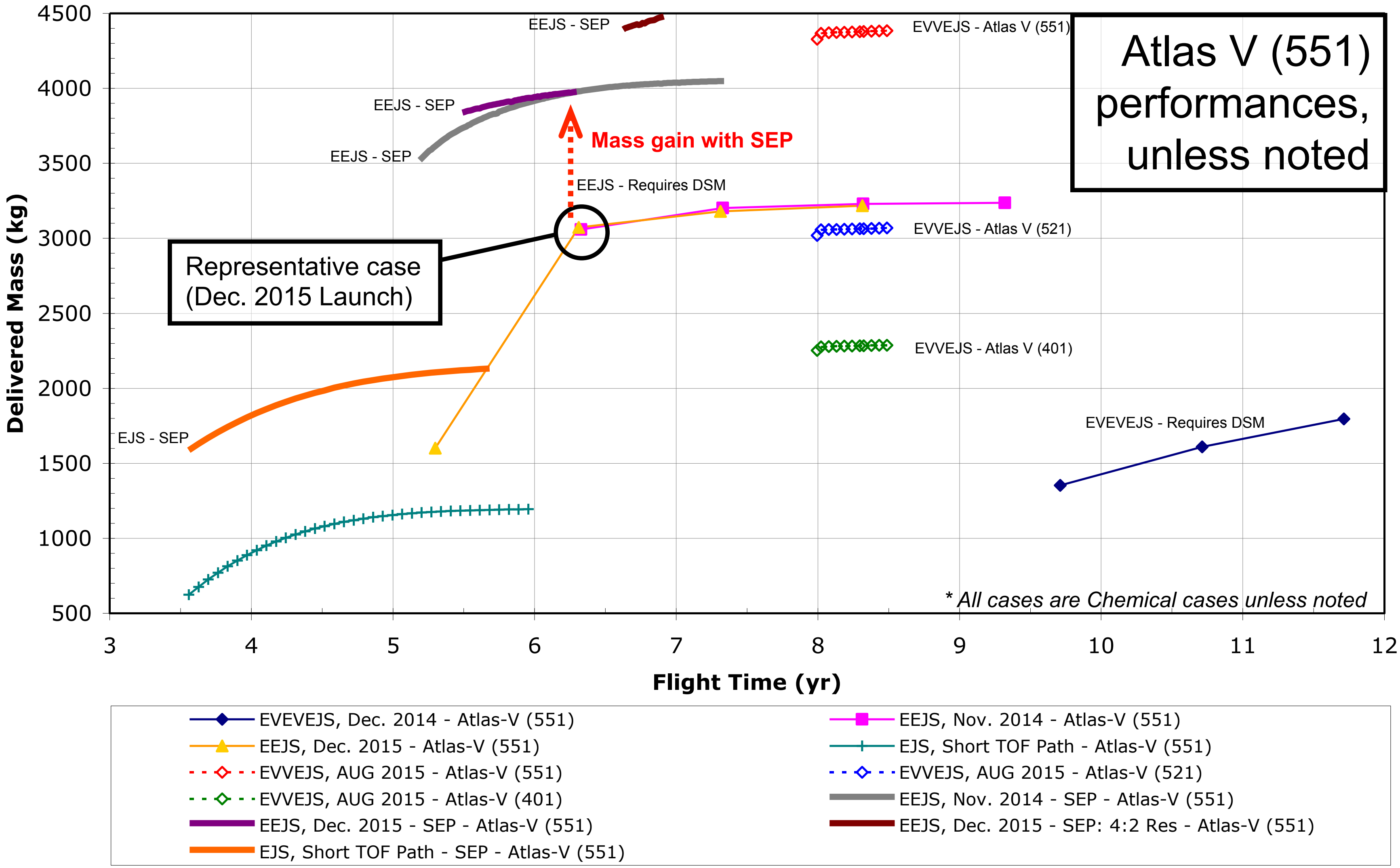
~10% reduction in delivered mass when the launch window accounts **for a 21 day launch period** instead of the optimal launch day

**Note that the “dry mass” calculation does NOT take into account ACS propellant requirements

Ref: Theresa Kowalkowski, Try Lam

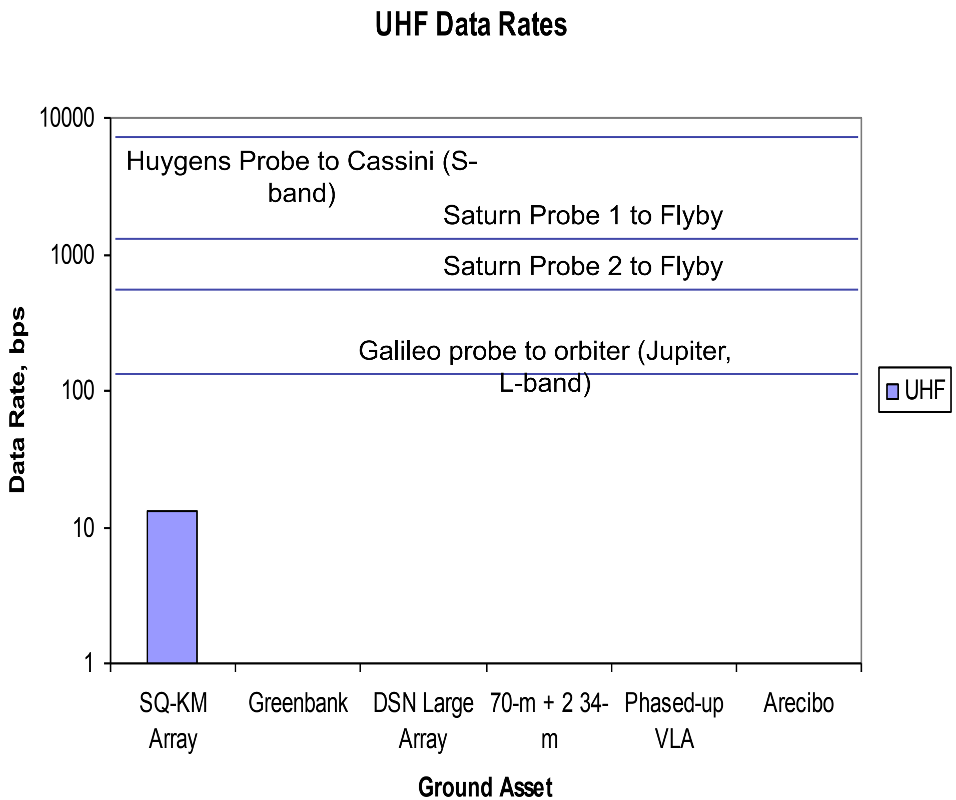
Trajectory Trade Space – Optimal Performance to Saturn for Atlas V

We assessed the trajectory trade space for a 2015 launch opportunity – baselined the 6.3-year cruise



Ref: Theresa Kowalkowski, Try Lam

Direct-to-Earth from Saturn using UHF & Assumptions



DTE Ground assets considered:

- 1 SQ KM Array – does not yet exist
- Greenbank 100-m
- DSN Large Array
  - Does not yet exist
  - Would need upgrading to UHF
- 70-m – would require upgrading to UHF
- 34-m – would require upgrading to UHF
- Arrayed 70-m plus two 34-m's
  - Would require upgrading to UHF
- Phased-up VLA
- Arecibo
  - During mission, Saturn declination is outside Arecibo's range

UHF Link Assumptions:

- UHF 401 MHz Frequency half-duplex
- 6 dB data channel margin
- Assume one hour of data acquisition (transmission of data during probe descent)
- Signal Characteristics (Electra heritage)
  - PSK Bi-phase
  - 60 deg modulation index
  - Convolutional (7,1/2) with Reed-Solomon Coding with convolutional interleaver
- Probe transmitter/antenna
  - 20-W RF (Requires Electra NRE, Jupiter probe assumed 92-W)
  - LGA transmit antenna (boresight along spacecraft axis) assumed nominal gain pattern
  - Assume Earth direction along LGA boresight
  - Assumed probe LGA boresight aligned with local vertical
  - 0.5 dB circuit loss (assume single strings on two redundant probes)
  - Assume RF-transparent parachute
  - Pendulum oscillation motion of probe/parachute system not yet accounted for (may lose link during oscillation)
- Saturn Atmospheric Attenuation
  - 1.5 dB along the vertical corresponding to tau = 0.35 (Ref. Tom Spilker provided chart)
- Saturn Hotbody
  - About 400K at UHF – resultant temperature increase is small (< 5K) at UHF for SQ KM at Saturn-Earth distance
- Ground Aperture
  - 50% aperture efficiency
  - Cooled receiving electronics

Notes – Additional atmospheric attenuation at S-band is prohibitive. For Arecibo, Saturn is outside dec range

Update Slide with new figures from Dave M.

Ref: David Morabito